ALLEGANY BALLISTICS LABORATORY

HERCULES POWDER COMPANY
Cumberland, Maryland

U. S. NAVY
Bureau of Naval Weapons
Contract NOrd 16640

ABL/X-69

The Diesel-Powered Ballistic Centrifuge

October 1961

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This report was delivered at a JANAF meeting, October 9, 1961, by Donald Brown of ABL. Following the address 50 copies were distributed as handouts to interested listeners.

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ABSTRACT

Allegany Ballistics Laboratory has designed and constructed a centrifuge for use in ballistic and physical testing of rockets and rocket components. Certain flight conditions can be simulated by centrifuging a rocket either ignited or unignited. Depending upon the size of a rocket or a component, forces up to 55 g can be applied.

Upon approved request, this centrifuge can be made available to outside agencies.

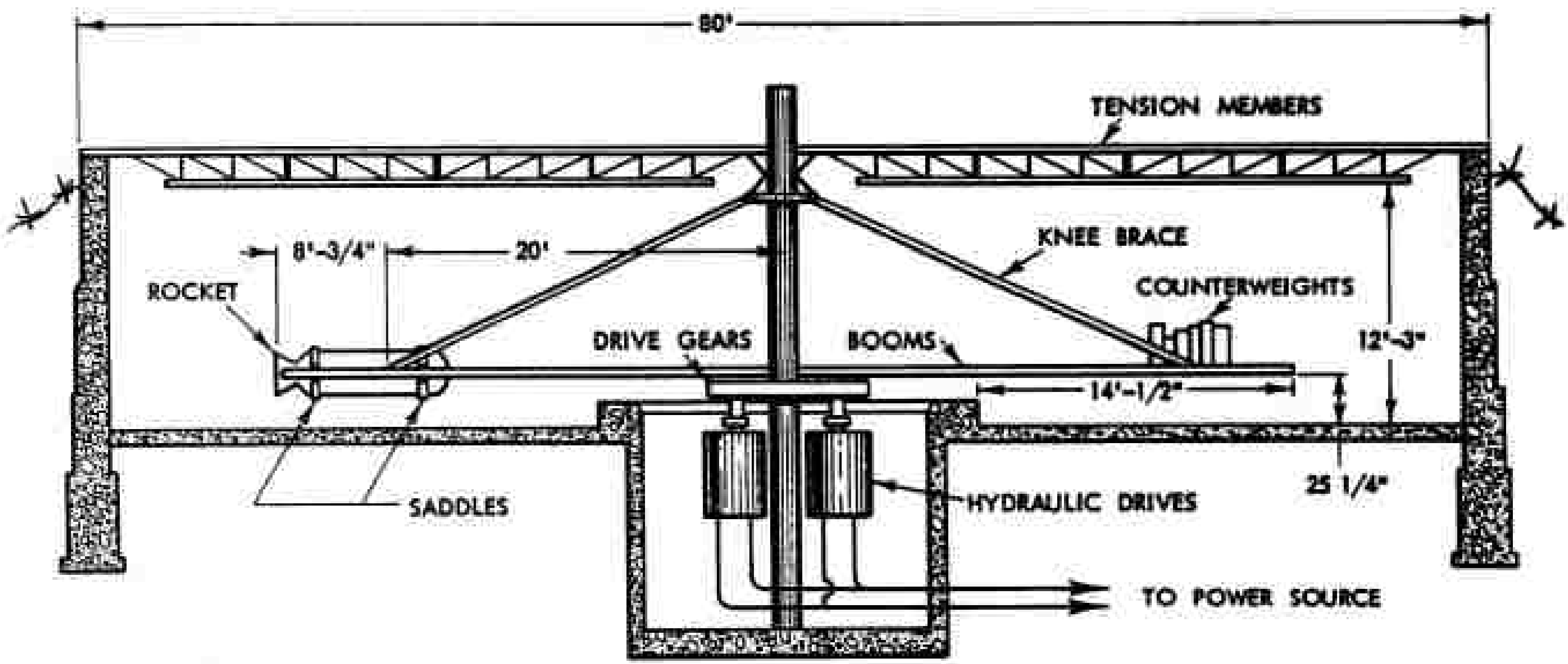
INTRODUCTION

The components of a rocket unit include relatively fragile items which may be damaged when subjected to loads which may result from acceleration. In the early days of rocket development, flight testing of missiles was the most effective method to determine the effects of acceleration loads on a rocket unit or its components. Consequently, Allegany Ballistics Laboratory (ABL) rockets were shipped to suitable ranges in the western United States for flight testing. This, of course, resulted in extra time and transportation costs. During such testing the rocket unit or component was usually ruined or lost and therefore provided little information regarding any failures.

ABL became convinced that centrifuge testing would simulate flight test conditions for many of the rocket components under study and could give better results at a saving of time and money. As no equipment of a suitable size and strength was available in this country, ABL designed and constructed a centrifuge facility which has been in operation since 1950.

Since its construction and successful use, the ABL centrifuge has saved valuable time and dollars at this Laboratory. Its primary activity has been testing rockets and rocket components. However, other items have been tested on it under high-acceleration conditions. Several outside facilities have also brought equipment to this laboratory for centrifuge testing. The centrifuge facility has been used to solve problems and to obtain information which otherwise would have required flight testing or might have been unobtainable.

This report describes the centrifuge equipment in operation at ABL.



Cross Section of Centrifuge

GENERAL DESCRIPTION

The centrifuge is mounted in a circular pit 80 feet in diameter. A separate building adjacent to the pit houses the 500 brake horsepower diesel engine used to supply hydraulic pressure to operate the drive motors located in the pit itself. Recording and control equipment are located in the instrument house approximately 150 yards from the centrifuge.

ENCLOSURE

The reinforced concrete wall around the centrifuge is 15 feet high and the thickness tapers from 16 inches at the base to 8 inches at the top. This wall surrounds an area about 80 feet in diameter which is floored with reinforced concrete. Two hydraulic motors located in a pit in the center of the floor rotate the centrifuge booms through drive gears.

A stationary center post, firmly braced in all directions against the concrete wall, serves as an axle on which the booms rotate. Each boom is constructed of two parallel 5-inch-diameter steel tubes 28 feet long. These two parallel tubes are securely attached to each other through the lower bearing housing and are supported by 5-inch-diameter steel tubes (knee braces) attached 7 feet from the boom end and terminating at the upper bearing housing which provide free rotation around the center post. Clamps, upon which a rocket may be mounted for testing, are attached near the end of one boom. Counterweights, whose weight and position depend upon the mass of the test object, are mounted near the end of the other boom.

POWER TRAIN

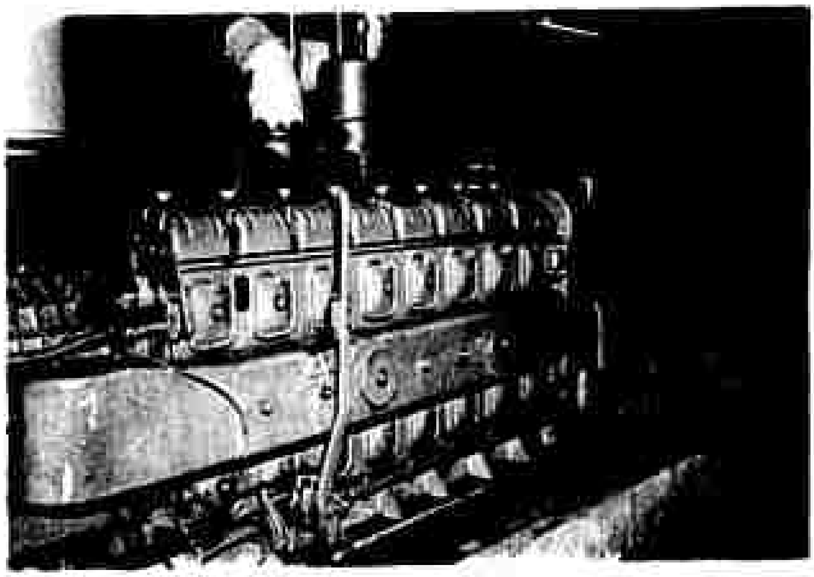
The power source is a diesel engine capable of producing 500 brake horsepower. This engine drives a large variable displacement pump which forces oil through 6-inch diameter pipes to drive two constant displacement hydraulic motors located in the pit in the center of the centrifuge enclosure. These motors rotate the booms through two large drive gears. The variable displacement pump, located in the diesel house, is termed the A end of the hydraulic system. The two constant displacement hydraulic motors and bypass valves located in the centrifuge pit are termed the B ends of the system.

The hydraulic system (A end and B end) was built for the U. S. Navy by the Waterbury Tool Company to drive a 16-inch gun turret. This equipment had become Navy surplus and was supplied to ABL for the centrifuge project.

SPEED CONTROL

The power from the diesel engine is transmitted to the variable displacement hydraulic pump through a speed reducing transmission. The setting of a tilt plate at the A end regulates the piston stroke within the cylinder, thus varying the oil flow in the line to the B ends. Variation of this oil flow controls the speed of the B ends' motors and, through the drive gear, controls the rotational speed of the

centrifuge booms. The hydraulic pressure in the system is kept from exceeding 1525 psi. by means of a bypass relief valve in each B end.



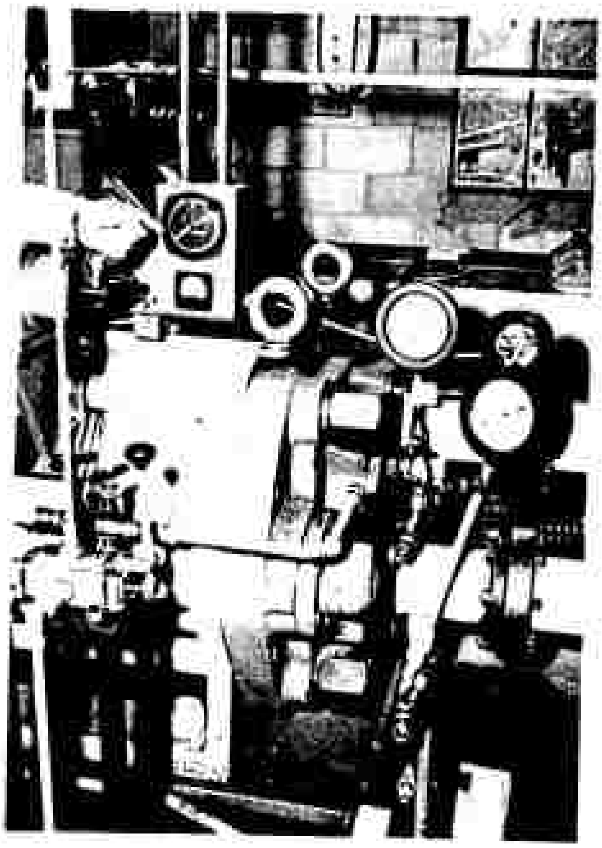
Diesel Drive Motor, Transmission, and Hydraulic Pump (A-End)

One of the Two Hydraulic Motors (B-Ends)

The maximum operating speed of the A end is 350 revolutions per minute (rpm) which is produced by a diesel speed of 890 rpm. The diesel speed is controlled by a governor. Through the combined effect of the diesel governor and the tilt plate on the A end, the centrifuge booms can be controlled at any desired speed up to 80 rpm. At a boom speed of 80 rpm, a rocket mounted on the boom with the rocket center of gravity (cg) located 20 feet from the center post will be subjected to an acceleration of 43 g.

Two tachometers, one in the diesel house and one at the firing switch in the instrument house, indicate diesel speed readings at all times. Another tachometer at the centrifuge control panel in the diesel house is used to indicate the centrifuge rpm. It can easily be read to 1 rpm. This instrument shows the operator when he has reached the desired speed. An accurate recording of the speed of the centrifuge is made in the instrument house during a test.

For safety reasons no one is permitted in the diesel house if the rocket under centrifuge test is fired.



Control Point for Boom Operation

RECORDING SYSTEM

A slip ring and brush arrangement provides ignition and intelligence circuits between the centrifuge and instrument house. Thirty-four silver-plated rings mounted on the stationary center post provide ten information channels and five command channels between the centrifuge and instruments. Silver impregnated carbon brushes secured to the lower bearing housing of the centrifuge are in constant contact with the stationary rings during rotation of the boom assembly. Silver impregnated brushes are used to keep frictional interference and contact resistance at a minimum.

Strain type pressure gages are attached to the rocket chamber when it is mounted on the centrifuge. During firing, the rocket chamber pressure signal is transmitted from the gage through the brush ring system to an oscilloscope in the instrument house. A constant speed drum camera photographs the face of this oscilloscope to provide pressure-time records. A time base is recorded on the same film.

A commutator is mounted on one of the B end hydraulic motors. The commutator speed varies with the speed of the motor shaft and the commutator output becomes a signal voltage to indicate rotational speed of the centrifuge. The commutator signal is delivered to a second oscilloscope in the instrument house. The face of this centrifuge-speed oscilloscope is also photographed on a constant-speed drum camera. A time base is also recorded on this film.

LOADING AND LIMITATIONS

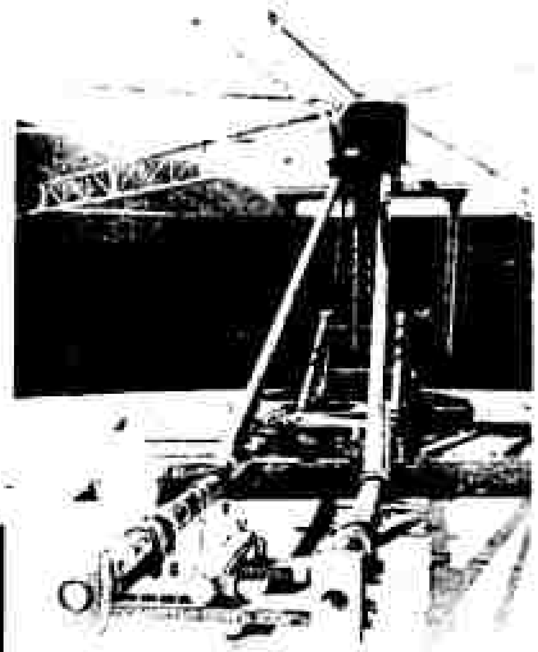
The centrifuge is designed to withstand a maximum horizontal force of 200,000 lb. That is, when a rocket is being fired during centrifuging, if the centrifugal force of the rocket and its attachments is balanced by that of the counterweights, the permissible inward (toward center post) thrust of the rocket would be 200,000 lb. Due to the difficulty in accurately aligning the longitudinal axis of the rocket with the longitudinal axis of the boom, and to provide a safety factor, a maximum calculated inward force of no more than 100,000 lb. is permitted. The inward force is determined by subtracting the centrifugal force from the rocket thrust. In these calculations the radius is the distance from the center post to the C. G. of the rocket. During burning, the propellant mass is decreasing and the C. G. is changing; therefore the calculations are based on the weight of the propellant at the mean, or half-burned, point. At a radius of 20 ft., a maximum acceleration of 43 g at a maximum speed of 80 rpm can be obtained.

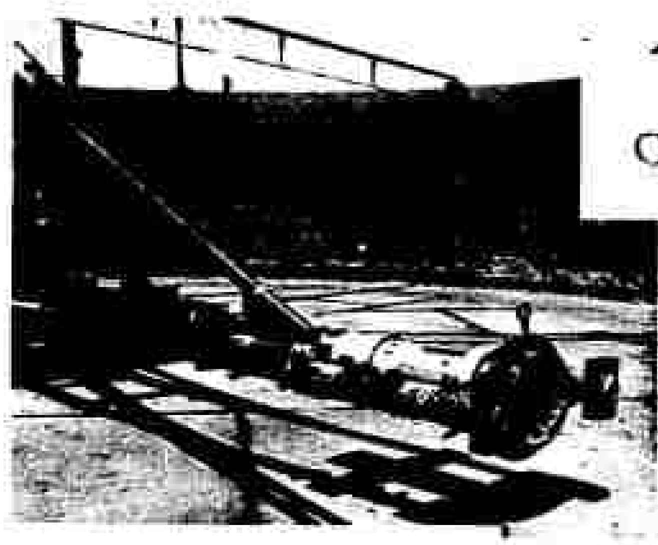
The permissible load at the boom tip is governed by the allowable bending moment at the section where the knee brace joins the boom. This allowable bending moment has been calculated at 290,000 in.-lb. From this calculation the maximum load is found to be 3000 lb. at the boom tip. The permissible load value increases rapidly as the C. G. of the load is moved inward along the boom; reaching a maximum value of 50,000 lb. when the load C. G. is placed at the junction of the knee brace and boom.

Maximum size of motors to be tested are summarized below:

TYPE OF TEST	LENGTH	DIAMETER	WEIGHT
Spin firing	14 ft.	30 in.	6,000 lb.
Spin only	9 ft.	6 ft.	20,000 lb.

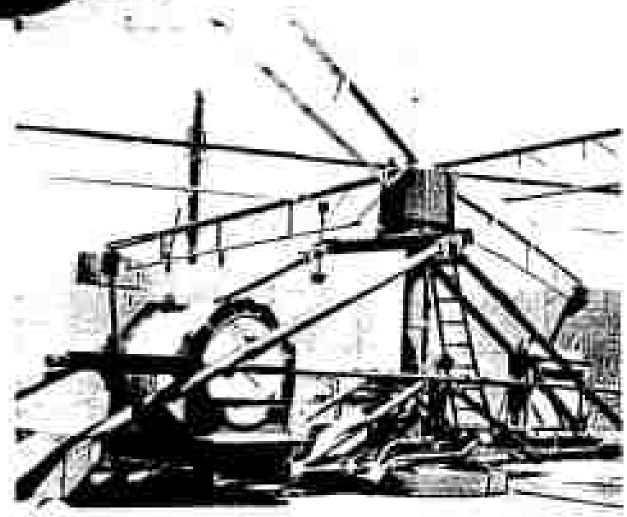
Centrifuge Adapted for Small Size Rocket





Average Size Rocket Mounted for Longitudinal Force

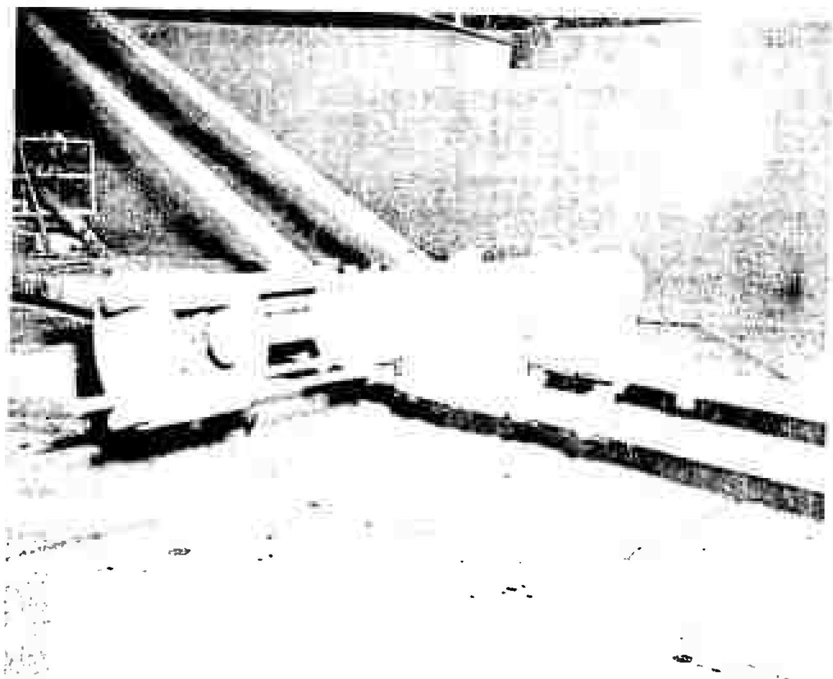
Large Size Rocket Requiring Special Mounting Fixtures and Counterweights



The rocket is secured with heavy clamps which are located between the two arms of the boom. In this position the C. G. of the rocket is approximately 20 feet from the center post, and the longitudinal axis of the rocket is approximately in line with the longitudinal axis of the boom. Dependent upon weight and thrust limitations, rockets as large as 14 feet long and 30 inches in diameter may be accommodated in this manner.

During centrifuging, the head of the rocket is pointed toward the center post. The inward movement of the rocket is prevented by a thrust crossbar which is held in place by two stops welded to the boom. The rocket is restrained from moving outward by the heavy clamp in the vicinity of the joint between the rocket chamber and the nozzle approach section. The chambers of various diameters may be accommodated by the selection or fabrication of an appropriate adapter for this clamp.

To subject a rocket to a lateral centrifugal force the unit may be attached in the same plane but perpendicular to the longitudinal axis of the boom. Rockets have been centrifuged in this position but may not be fired in this position unless provided with an approved thrust neutralizer. When in this position the firing of the rocket is restricted by the amount of torque to which the driving gears may be subjected.



Average Size Rocket Mounted for Lateral Force
Note: Thrust Neutralizer

TESTING OF ROCKETS AND COMPONENTS

For testing a rocket on the centrifuge at a nonambient temperature, a definite procedure is followed to minimize the time lapse between removing the rocket from the temperature conditioning box and firing. The lower halves of all of the boom clamps (saddles) are first mounted on the centrifuge boom and the nozzle saddle is located at the proper distance from the thrust crossbar mount.

To counterbalance the weight of the test object, weights are located on the opposite boom. If the unit is centrifuged and not fired the total weight is counter-balanced. If the rocket is to be fired during centrifuging, all the inert weight plus half of the propellant charge weight is counter-balanced. The instrument channels and the firing circuit are then checked. The rocket is then brought from the conditioning box and positioned on the boom; the top halves of the boom clamps are secured, the centrifuge is brought to the desired speed and the rocket is fired.

All tests are made at a constant boom speed corresponding to a constant flight acceleration. Although in actual flight the acceleration is not constant, the maximum acceleration to which the unit would be subjected is usually the one of most interest.

COMPONENTS TESTED

In addition to testing rockets, the centrifuge has been used in testing the following: (1) trigger mechanisms designed to trip at certain accelerations; (2) pressure relief assemblies designed to trip at certain accelerations; (3) propellant grains at various conditioning temperatures (especially low temperature); (4) grain immobilizer devices under load; (5) obturations under load; (6) igniter cases; and (7) electronic guidance equipment and other missile components.

CONCLUSIONS

Through the use of the ABL centrifuge an immeasurable saving in money and time has been realized by this Laboratory as well as outside contractors.

The ABL centrifuge is available for use by any government contractor with proper clearance who wishes to take advantage of the facility.

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